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VOLUME VIII
Number 6

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UNIVERSAL TEST ENGINE
GOURDOU-LESEURRE PURSUIT PLANE
DIRECTIONAL STABILITY OF AIRSHIPS

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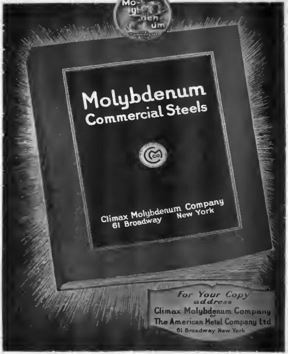
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VOL. VIII. NO. 6

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THE GARDNER-MOFFAT COMPANY, Inc., *Publishers*

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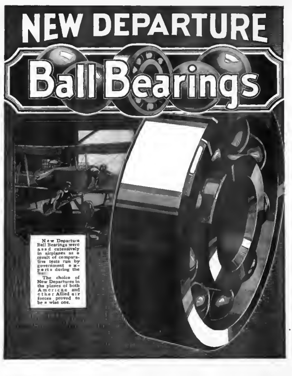

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Vol. VIII April 15, 1920 No. 6

THE Aeronautical Show which opens on April 21, at San Francisco is the first affair of this kind ever held on the Pacific Coast. As such it will undoubtedly attract a large number of visitors whose practical acquaintance with aeronautics was hitherto restricted to seeing various Army airplanes in the sky or on the ground. A convincing demonstration of the stage aviation has now reached in its application to the demands of air transport was hitherto lacking in that important section of the United States. The coming Aeronautical Show will fortunately correct that deficiency and the Manufacturers Aircraft Association—to whose untiring efforts the exposition will owe its existence—is to be congratulated for having taken this step, which is in keeping with its far-sighted policy.

It is therefore to be hoped that the Show will do much to arouse the Pacific Coast to the realization that aircraft offers a means of communication superior to any other in the matter of speed, and fully comparable as to safety and comfort.

Inclination of Wings on Sand Test

At the present moment there is a feeling amongst engineers, that the commonly used inclination of 14 deg. on sand testing is excessive, and that 7 or 8 deg. would be a more correct figure.

When the 14 deg. inclination was first employed in this country, the precise figure was fixed on no very sound theoretical basis, but was chosen to conform with French practice, and to impose a heavy drag load on the truss, as drag loads seemed to be the cause of the most serious trouble in flight.

The inclination of 14 deg., however, tends to impose a greater drag on the wings than would be present even on the steepest of dives at terminal velocity, and a much greater drag load than is present on recovery after a dive.

It would seem as if decreasing the inclination of the wings on sand tests would be a step in the right direction.

Maintenance of Flight in Twin Engine Machines

Recent experimentation on propellers indicate that a propeller, whether at rest, or rotating slowly as a wind mill, may have quite a considerable negative thrust coefficient. This negative thrust coefficient may be in the neighborhood of 20 per cent of the thrust coefficient of the propeller under ordinary flight conditions.

This result is not unexpected by engineers, and has an important bearing on the question of maintenance of flight for the twin engine machine with one motor out of commission.

It has sometimes been thought that in order to determine the possibility of flight on one motor, all that was necessary was to draw the usual required horse power curve, and half the horse-power available. Unfortunately, this is much too favorable an assumption.

With one motor, there is considerable rudder control required which in turn means banking, and consequent loss of sustention. If the motor is just turning over and firing, its thrust coefficient may be zero, but if it is completely at rest or revolving slowly as a windmill, it will produce a large negative thrust, which will result in an appreciable decrease of available power.

This point requires very careful consideration in the design of twin engine planes and in testing them it would seem particularly important to have one motor completely out of commission, and not revolving at a low speed as has been customary.

Radial Air-Cooled Motors

The recent specifications issued by the Engineering Division of the Air Service, mark a very important development. Although the stationary air cooled motor has not yet got beyond the controversial stage, there is no doubt that such engines are destined to play a very important part in all future airplane development.

The Air Service, while no doubt realizing to the full extent the success that the British constructors have achieved in this field, is very wisely calling on the best American talent, so that the problem may be tackled independently on this side.

The specifications call for a very high standard of achievement, but, at the same time, give the designer great independence of action. A brake horsepower of between 350 to 370 is called for at 1,800 r.p.m. of the motor. This probably is as good a coordination as the airplane designer can hope to have. The fuel consumption called for must not exceed .58 lb. per b. hp. hour, which is a moderately liberal figure. The engine must not weigh over 2 lb. per b. hp. at normal r.p.m. The maximum diameter is not to exceed 50 in. The tests imposed are extremely severe, and include a 50-hr. endurance test.

Builders are given plenty of time for the development of the engine and no doubt remuneration will be on a liberal scale.

It is extremely gratifying to see this important development started by the government on such satisfactory lines.

Universal Test Engine

By Glenn D. Angle

Engineer in Charge of Engine Design, Engineering Division, Air Service

Engineers will generally agree, that despite the marvelous progress made in the development of high speed internal combustion engines during recent years, there still remains much to be accomplished toward increasing efficiencies and improving designs generally. The demands for better motive power previously brought forth new ideas effecting improvement so rapidly, that although many of the engines in use at present are of reputedly good design, there is scarcely any reliable and accurate scientific data which could be used in forming a proper basis for comparison.

One must take into account, however, that there are many influencing factors so dependent upon each other that an individual analysis of each source is practically impossible. Furthermore, engine designs are usually of such a varied nature that only the most pronounced differences in performance will permit of opinions regarding the effects of certain combinations. Nevertheless, something should be done as this lack of substantial data not only hinders scientific progress but generally leaves the engineer in a quandary in selecting the designs or combination of designs that should produce the results expected in a most efficient manner.

As a rule, the mechanical efficiency of an internal combustion engine is comparatively high. This is particularly true of the airplane engine, which is accurately constructed of very light weight parts made from the highest grades of material. Apparently little opportunity for improvement is afforded in this direction, but the marked differences between weight-power ratios, fuel consumptions, and other important performance characteristics clearly demonstrates the need for extensive development along other lines. One of the most important of these is undoubtedly the design and construction of the cylinder and its adjunct components.

Heretofore, the development of a cylinder has been carried out on a complete engine, but seldom produces satisfactory results as quickly as desired. Moreover, for multi-cylinder forms, such a method of development obviously entails considerable expense. Under normal conditions, one cylinder of an engine functions exactly like the others, and improvements in one effect improvements in all, hence, cylinder development can be carried out just as successfully, and with much less difficulty or expense, on a single-cylinder engine constructed for the purpose. A few test engines of this sort have been built, but in every case were intended only for one design and the field of experimentation was thus limited to that particular cylinder. Whenever it was required to develop other sizes or designs, new test engines had to be constructed. The Universal Test Engine surmounts this difficulty, as it is so designed that most any cylinder can be tested on it, but before describing this engine it would be well to briefly explain the specific reasons for its design.

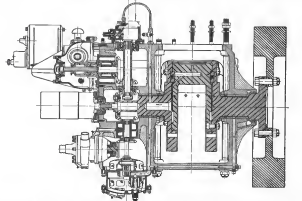


Fig. 1 Longitudinal Cross-Section of Universal Test Engine

Immediately following the signing of the armistice, the organization of the Governmental Experimental Airplane Station at McCook Field, Dayton, Ohio, began to rapidly adjust itself to the new duties, which included principally the perfecting of certain airplanes and engines then on hand, and as a technical division to accumulate data and prepare designs for future construction which should place this country in its proper rank in the science of military aeronautics.

Since engine development should precede plane development by one year or more, it was clearly evident that a good engine program was of the utmost importance. Only a few American designs were considered of military value and so besides immediately undertaking the necessary improvements on these engines, the design of other types found to be needed was also placed under careful consideration.

For future designs it was very apparent that the former methods of development were entirely inadequate, and the desired results could hardly be expected with the limited amount of money available for this work. It was therefore decided to construct some sort of engine which would allow for accurately testing different sizes and designs of cylinders under varying conditions, so that the performance and consequently the value of any particular design could be determined before constructing an entire engine. Furthermore, the Engineering Division could become acquainted with the exact performance of any cylinder submitted by the manufacturer of an experimental engine prior to purchasing the complete unit.

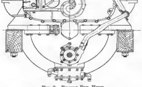


Fig 2 Timing End View

No knowledge concerning any former construction of this sort existed; consequently, the practicability of building an engine for these purposes demanded serious consideration. It was not until after the entire situation had been very carefully analyzed that design and construction was actually undertaken. It was proposed to obtain as wide a range of bore-stroke combinations as practically possible, provide for the operation of all types of cam and valve mechanisms, and at the same time allow for quick interchangeability of parts and easy means for testing.

The salient feature of the engine as it was finally worked out is the wide range of cylinder adaptation. Cylinders can be tested which have bore diameters from 4 to 8 in., inclusive, and strokes from 4 to 10 in., inclusive. This range includes all sizes of airplane engines that are at present in practical use, and allows for experimentation with large cylinders if future requirements so demand. Compression ratios can be readily varied, in most cases it being quite easy to obtain a range from 4 to 10. Obviously, high compression ratios can not be used continuously near the ground, but provision was made for such cases when it might be desirable to determine the affects of different compressions at various altitudes by testing a cylinder in a vacuum altitude chamber. All other outstanding features can best be explained in the description of the various parts which immediately follows.

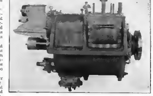


Fig 3. Side View of Universal Test Engine

Crankcase

The crankcase is made in halves and divided along the horizontal crank center-line in the conventional manner. Both upper and lower halves contain the crankshaft bearings and the two are held together mainly by four long and sturdy bearing studs, together with the four shorter bearing bolts. There are also additional bolts through the outer flanges which give an oil tight joint. The walls, and in fact all sections, are made extremely heavy. The casting, which is made of iron, produces a very rigid frame member and should prevent serious damage in case any rotating part fails.

The crank and gear compartments are separated by a wall so that the gears are not exposed to the crankcase vapors. On either side of the crank compartment are large hand holes which permit inspection and the adjustment of connecting rod bolts. When the engine is in running condition these inspection holes are covered by breather elbows retaining screens which are to prevent oil vapor from being blown out or any foreign substance from entering the interior.

Crankshaft

A great deal of thought had to be given the design of a crankshaft for this engine on account of various lengths of strokes which were to be used. Individual crankshafts could

Fig. 4. Upper Half of Crankcase

Fig 5 Lower Half of Crankcase

have been made for each length of stroke, but this undoubtedly would have introduced difficulties later on. Bearings would have to be refitted almost every time a shaft was changed, and a conventional shaft design, in order to be strong enough for the large bore-stroke combination, would not be well proportioned for the smaller combinations. Furthermore, the attachment of counterweights to every shaft would each time introduce vital design problems.

The built-up crankshaft construction, shown on Fig 6, eliminates the disadvantages referred to, and has another feature in that it serves to supplement the action of the regular flywheel and thereby helps to maintain a more uniform speed of rotation.

The crankshaft assembly consists mainly of three major parts. The two end portions include the main journals integrally attached to the large discs which have eccentric recesses for receiving the intermediate piece. One end portion has a flange for attaching a flywheel and the other a flange for a bevel gear which drives the various auxiliary units. The intermediate section comprises a crankpin on the ends of which are eccentrically formed similar and integral discs of the proper diameter to fit flush into the recesses provided in the larger discs of the end sections. The eccentricity of the recess is the mean of the maximum and minimum crank radii required to give strokes previously specified. By angular adjustment of the intermediate section it is clearly evident that varying crank radii can be readily secured.

The three crank sections are held together as one assembly by a total of 12 bolts, 6 on each side. These bolts have countersunk heads, set in flush to the inner surfaces so as to avoid any interference with the connected rod, and are retained by slotted nuts and cotter pins. The bolts are not in shear, as the driving torque is carried by blocks or dowels which fit snugly into small recesses on both sides. To facilitate removal, each dowel is provided with a tapped hole.

Counterweights are bolted on the crankpin side of the large discs of the end sections by means of holes provided in those portions outside the eccentric recesses. The holes are unevenly spaced so that it becomes impossible to incorrectly attach counterweights from some predetermined location. The weights are of such proportions and the centers of gravity are so located from the crank center, that the crankshaft assembly in addition to being in static balance provides for the balance of half of the reciprocating inertia forces. As is generally understood, partial balancing of this sort on a single cylinder engine can be accomplished only at the expense of introducing an unbalanced component of equal magnitude along the horizontal. However, as a result, the forces are least if considered in every direction.

A variable throw crankshaft is apparently very difficult and expensive to produce, but once made, it has an indefinite period of usefulness. And when supplied with an additional intermediate section for strokes in half inches, it serves for testing purposes much better than would fourteen or in other words the equivalent number of crankshafts necessary to give that many stroke lengths. Even without any special tooling, the first crankshaft of this design was so accurately machined, that when assembled it had much better bearing alignment than the average crankshaft made in one piece.

Connecting Rods

It became necessary to provide for more than one length of connecting rod on account of the limits to which a piston can overrun the cylinder skirt, but it was found that only one rod was needed for each even inch stroke length. The body of the rod for each particular length of stroke was established by the section required to keep the stresses within safe limits with the largest diameter cylinders which were likely to be used, and also clear the skirt of the smallest cylinders, whose diameters in each case should not be less than the stroke length.

Since the crankpin diameter is never changed, the crankpin bearing is the same for all rods and made of sufficient length to satisfy all conditions. The upper end of the rod is likewise made amply large and a bushing inserted to give the desired diameter of piston pin bearing. The width of the upper end is limited by the length of bearing required in the smallest piston that would probably be used with each stroke, and by careful analysis it was found possible to so proportion these bearings that at no time were practical unit bearing pressures exceeded.

Camshafts

It was necessary to provide two camshafts in order to test all types of L or T head, or in fact any cylinder designs, whose valve gear is operated through push rods from a camshaft mounted in the crankcase. These camshafts were symmetrically located on each side of the case, and at a distance from the center sufficient to allow for operating the valve gear of the largest cylinder which could be tested. The shafts are driven through spur gears, as will be noted from Fig 7. An idler gear is mounted on a stud between the driving and driven gears, and can be easily removed when the particular camshaft which it drives is not to be used. The camshaft gear is held to a flange on the shaft by three screws. By providing a certain different odd number of holes in each piece, a very fine degree of adjustment for timing purposes is had.

The shaft is supported in three split aluminum bearings which are assembled onto the shaft before it is inserted into the crankcase from the rod. When the assembly is in place the bearings are held from turning by the hollow studs, through which oil is supplied under pressure.

That part of the shaft extending into the crank compartment is splined for the purpose of driving cams. Individual cams of any desired shape or size having the proper splined hole may be attached. These are held in the correct longitudinal positions by spacing sleeves which slip over the outside of the splines. The whole assembly is then clamped together by means of a nut drawn up tightly against the steel collar which serves as the rear bearing of the camshaft.

Push rod guides are usually of special design depending of course upon the particular requirements. The push rod guide housings are bolted on top of the crankcase, over a hole directly above the camshaft. When these housings are not to be used the holes are covered by plates.

Fig 6. The Built-Up Crankshaft Construction

Overhead camshafts are to be considered as a part of the cylinder design, and therefore need no description here. However, attention should be directed to the fact that the scheme for attaching cams is again carried out, even so far as to use the same size of splines, thus making it possible to adapt the same cams in either place.

Flywheel

The purpose of the flywheel as is quite generally known is to contribute toward smoother running and lower rotative speeds, and comes as the result of storing the energy created during periods of high torque to compensate for the low torque periods. We have in this engine the possibilities of comparatively high and low torque magnitudes and also a wide speed range, if considered as controlled by the so-called limiting piston speeds. A flywheel having a sufficient moment of inertia to handle the greatest torque periods, if made very large in diameter, would undoubtedly have prohibitive peripheral speeds in certain cases. It was found possible, however, after several trial computations, to satisfy all conditions with only two sizes of flywheels. These were so designed, that at no time should the engine be prohibited from running at its lowest speeds more than 300 r.p.m.

Lubrication

Lubrication is of the force feed dry sump type, oil pressure being maintained by a slightly altered Liberty oil pump mounted on the lower part of the crankcase. The only alteration on the pump is the addition of an exterior adjustment for varying the pressure of the relief valve spring. This provides simple means for regulating the oil pressure which is maintained in the line serving the crankshaft journals. Sufficient outside connections were incorporated so that oil could be led to any one or all of the camshafts, the tachometer gear housing, the gears and bearings used in conjunction with driving all of the various units and also to an oil gauge.

Ignition

Either battery or magneto ignition may be employed. A Liberty generator is supported on the crankcase and driven through splines at the end of the crankshaft, and when not in use is to be replaced by a cover plate which fits its mounting flange. Distribution for battery ignition is taken care of by magneto replacement units mounted on the magneto base flanges.

The gear case cover provides space for mounting and driving four magnetos or four magneto replacement units as desired. It is reasonable to believe that as cylinder bore dimensions are increased the use of more spark plugs per cylinder should

Fig 7. Timing End with Magneto Housing Removed

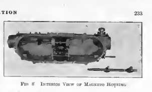


Fig 8 Interior View of Magneto Housing

improve performance as a result of the better flame propagation. By supplying at least four spark bosses per cylinder, it will be possible to verify the relative values of the different numbers of sparks. Also, the proper location of spark plugs in any particular cylinder design may be determined by running tests with plugs in various positions. It is a comparatively simple matter, during the test of cylinders using dual ignition, to have both magneto and battery systems connected up, and by switching from one to the other note the effects and make comparisons as to the merits of the two systems under identical conditions. It is also proposed in connection with this engine to run tests to determine the values of various intensities of spark.

In order to derive full benefit from multiple ignition, it becomes important to have the sparks occur simultaneously. All magnetos, therefore, should be advanced together from a common point, and the advancing apparatus should have no slackness in its movements. All magnetos are driven through bevel gears from cross shafts whose squared ends engage with a central and permanently mounted shaft having an integral spiral gear. The angular positions of the three in line shafts are varied by sliding the driving spiral gear forward and back on the driving splined shaft. The driving gear is operated by a yoke which is pinned to a small shaft extending just outside of the housing for hook up to an instrument board.

The cross shafts on either side of the center can be readily removed from the ends by first dismantling the covers which retain their ball bearings. This feature is important as two shaft and gear assemblies are supplied in order to operate magnetos having either crankshaft or half crankshaft speeds of rotation.

It will be noted from the interior view of the magneto housing shown on Fig 8 that special means have been provided for accurately adjusting the magneto timing for spark synchronization. The magneto driving gear is not fastened to the armature shaft, but instead, floats on a hub that is keyed to this shaft. The drive is taken through the two adjusting screws, which are to be screwed up and locked in the correct position against an extension provided on the back of the gear.

When certain magnetos or magneto replacement units are not used, the hole through which these units are driven must be closed by a cover plate. This plate is held in position by a flat spring which at other times is turned back out of the way in a vertical position.

Cooling

For testing water-cooled cylinders, circulation is maintained by a centrifugal water pump identical to the one designed for the 4-cyl. Liberty engine. The outlet water from the pump is piped just beyond the first external crankcase rib, and from here connections are quite easily made to any desired point on a cylinder. In most every case it will be found that the capacity of this pump is greater than necessary, so, in order to assimilate the conditions under which a cylinder is cooled as a unit of a multi-cylinder form, means for regulating and measuring flow can be incorporated just outside the cylinder inlet.

When testing air-cooled cylinders, the water pump should be temporarily replaced by a special cover plate designed for this purpose. An air blast produced by a suitable blower is then directed against the cylinder walls for cooling. If suitable equipment is available, some very valuable data in regards to air cooling can be obtained in connection with regular cylinder tests.

Tachometer Drive

Whenever the dynamometer testing equipment does not include a tachometer, one may be attached and driven from the engine. The driving attachment is incorporated at the end of the gear and driving shaft shown mounted in the small housing on top of the crankcase directly above the gear compartment. This housing has three possible positions, allowing for drive toward the end of the engine, as shown on Fig. 2 or toward either side.

When side camshafts are used, the tachometer gear housing cover is in place and connected in the oil line for an original source of oil supply to the entire gear compartment. A flange containing a tube, which acts as the lower part of the telescoping housing around the camshaft driveshaft, is substituted for this cover whenever overhead camshafts are used. Oil is then supplied to the gear compartment by the overflow from the camshaft housing.

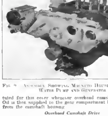


FIG. 9. ASSEMBLY SHOWING MAGNETO HOUSING, OIL PUMP, WATER PUMP AND GENERATOR

Overhead Camshaft Drive

Overhead camshafts are always driven through bevel gears. The driving pinion is keyed to a vertical shaft, having splines at its lower end to engage with the vertical hollow shaft mounted in the case. Three lengths of vertical camshaft drive shafts are all that are needed, to take care of the variation in height of camshaft above the top of the crankcase as influenced by cylinder design and by differences in bore-stroke combinations and compression ratio. Since the camshaft housing is usually supported on the cylinder, the drive shaft housing can be made to telescope. This allows almost unlimited privileges in the matter of raising or lowering the cylinder for any purpose.

Compression Ratios

As heretofore stated, compression ratios from 4 to 10 are possible. The ratios are varied by raising or lowering the cylinder in respect the crank axis, and in order to obviate any changes in a cylinder flange shims are employed. The crankcase has a large hole above the crank compartment in order to adapt cylinders of 8 in. bore. As a result, each cylinder must be securely mounted on a special flange which fits the crankcase, and is held down by means of the long main bearing studs and six additional studs of smaller diameter. All of these studs extend above the case for some distance to allow for shimming.

It was found possible to obtain the desired range of compression ratios in comparatively small increments, by the use of one or more of the six shimming plates of different thicknesses that were designed for that purpose. These shims, which have the same shape as the cylinder flange are fitted over the studs before the flange is put into place. Calculations are always made to determine the compression ratios that will be had with the various shim combinations when used with any cylinder adaptation and are recorded for reference purposes during these tests.

The above description dealing with certain features of the Universal Test Engine explains fairly well the numerous possibilities afforded for cylinder testing. Any cylinder within the prescribed size limitations, if more or less conventional in design, can be adopted, and moreover, in such a way as to assimilate very closely the conditions under which it is to perform as a unit of some multi-cylinder type. The flexible characteristics are not confined to cylinder sizes, but extend over each functionary element. This feature has been carried out as far as all former indications seemed to warrant.

Practically all comparisons will have to be made on a basis of the type of cylinder construction and then if desired, various cylinders compared for the purpose of determining the best construction for some particular kind of work. In a general way, cylinders must be classified and their performance judged accordingly.

Since the mechanical efficiency of this engine is low and brake loads are not in the correct proportion to those of multi-cylinder forms, it becomes necessary to reduce all data to indicated readings, which after all is the correct way to make these comparisons. After making due allowance for distribution, the brake horsepower of any combination of cylinders may be approximately calculated by totaling the indicated horsepowers of that many cylinders and multiplying by the probable mechanical efficiency as would be found in other engines of the same type running at corresponding speeds.

One of the design factors which engineers seldom agree upon, is the bore-stroke ratio. It should be possible after a sufficient number of combinations have been tried on this engine to make some kind of definite statement in this regard. Compression ratios are limited in a certain degree by the type of cylinder and the work to be performed, nevertheless these should be accurately determined for every case. The valve and cam design, which ordinarily requires extensive experimenting can be easily worked out with full assurance that the design adopted is the best possible under the conditions. Ignition tests, particularly in regards to number and location of spark plugs, are simple to perform and the results should be conclusive. Tests on cooling, whether by means of water or air, can be scientifically conducted and the data made applicable to the engine of which the cylinder belongs. Unless it is manifolding and gas distribution, there is apparently very little development work on cylinders which cannot be completely and accurately accomplished on this engine.

Two test engines were constructed in the shops at McCook Field and satisfactory tests have already been made on a few cylinders. One engine is kept running constantly and when a test is finished, this engine is removed from the dynamometer for a new cylinder adaptation, and the other engine takes its place. As a result of careful planning it is possible to so arrange the order of these tests that very little work is required in changing cylinders.

Several cylinder assemblies have been completed and are ready for test while a number of others are in course of construction. The results so far obtained, leave no doubt as to the practicability of this procedure, either in developing one cylinder or obtaining useful data on cylinder design generally. As more tests are completed, the easier it will be to compare the data acquired and arrive at conclusions, which no doubt may have considerable influence on cylinder designs in the future.

The Engineering Division is desirous of cooperating with anyone particularly interested in developments of this nature, and will furnish additional information upon request.

San Francisco Aero Show

The following is a list of the exhibitors at the San Francisco Aeronautical Show to date:—

Curtiss Aeroplane and Motor Corp
Goodyear Tire and Rubber Co
Dayton-Wright Division, General Motors Co
Glenn L. Martin Co
Loughead Aircraft Corp
Aeromarine Plane and Motor Co.
Boeing Airplane Co
Hall Scott Motor Car Co
Wright Aeronautical Corp
Standard Oil Co. of California
Interallied Aircraft Corp

The Air Service of the United States Army and Navy will be represented by a very comprehensive exhibit.

Absolute Pressure Gauge for Wind Tunnel Use

By Dr. J. G. Coffin

Director of Research, Curtiss Aerodynamical Laboratories

In the Curtiss wind tunnels the air speed determinations are based upon the readings produced by a standard Pitot tube on an absolute pressure gauge of great simplicity. This gauge replaces the well known Chattock gauge, a sketch of which is shown below for comparison.

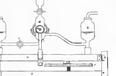


FIG. 1. SKETCH OF THE CHATTOCK MICROMANOMETER

A description of the Chattock gauge by J. C. Hunsaker is available in the "Reports on Wind Tunnel Experiments in Aerodynamics," Smithsonian Miscellaneous Collections, Vol. 62, No. 4. In our opinion, this gauge suffers from three disadvantages, one of which is that it is too sensitive when air speeds above thirty miles per hour are employed; another is that for great accuracy the centers of the liquid surfaces *A* and *C* are not invariable when the table is tilted through large angles, and another is that it requires three different liquids for its use and must be put into working condition anew after it has stood for a few days. Fluctuations in velocity at high speed render this instrument entirely too fussy for practical use. Our Chattock gauge is so sensitive that at an air speed of 45 m.p.h. it shows a change of air speed of .003 m.p.h., and at 90 m.p.h. a change of .001 m.p.h. This is several hundred times too sensitive. It is only fair to state that Dr. Chattock* devised the instrument for the precise measurement of very small pressures. An improvement on this instrument would be to connect *B* and *C* by means of a flexible tube, and simply raise *C* vertically, keeping *A* and *B* fixed. This would eliminate the second of the above objections, but its extreme sensitiveness is still a detriment.

The absolute gauge described below suffers from none of these disadvantages, it is always in working order and is amply sensitive for most wind tunnel uses. Two photographic views are shown in Fig. 2 and Fig. 3. The instrument is shown connected for use with the standard Pitot tube†, which can also be seen in the cut. Fig. 4 and 5 are scale drawings of the gauge.

In Fig. 4 *B* is a mahogany base and *A*, *A*, *A* are three wooden posts to support the brass reservoir *R*. The dimensions of this reservoir are so large that the change of level for any motion of the liquid in the glass tube *G* is inappreciable. As a matter of fact, since the liquid meniscus *M* is always maintained at the same place in the glass tube there is no real necessity for this precaution. However, as the gauge might be used at times allowing the liquid to move along *G* it is convenient to have a large reservoir.

The reservoir *R* is provided with two outlets *C* on top in the center and *D* at the bottom on the side. The lower outlet is connected to the lower end *V* of an inclined glass tube *G* which is attached rigidly to a mahogany disc *S*. This disc can be rotated about the axis *LL'* and be held in any position by the screw *N*. By changing the inclination of this tube almost any required degree of sensitiveness can be obtained. The static terminal of the Pitot tube is connected to the upper end of the glass tube *G* and the dynamic terminal to *C*.

The accuracy of the instrument depends upon the care given to the work on the steel rod *T*. This rod, which is screwed rigidly into the metal base plate *F*, is provided with a convenient number of accurately spaced holes, in our case thirty, at exactly half-inch intervals. In order to insure accuracy in the spacing of these holes, steel gauge rings were made, two of which had a hole in their sides, to be used as jigs for a drill and a plug. By having several of these rings of different lengths accurately known it is possible to drill and check the positions of these holes. They are accurately placed to less than a thousandth of an inch, which is ample for our purpose.

Two brass pieces *H* and *K* are fitted to slide without play on this rod. The upper one *K* has a vertical slot and is prevented from rotating by a plug *P*, but can move freely vertically through a distance of about two inches.

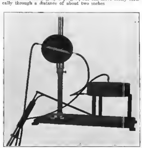


FIG. 2. CURTISS ABSOLUTE GAUGE AND PITOT TUBE

The lower one consists of two parts H_1 and H_2 and is essentially a micrometer. Its lower portion H_1 is rigidly fixed at any convenient height by means of the plug *P'*, the upper portion can be raised or lowered by rotation through a range of about three-quarters of an inch by turning *H*. There are ten threads to the inch, and the head being divided into one hundred parts, thousandths can be read off.

The height of the meniscus *M* above the level of the liquid in the reservoir can then be accurately determined. The remaining quantity necessary for the absolute determination of the air speed is the density of the liquid used. We have found alcohol, pure or diluted, to be very satisfactory. The density of the liquid is determined for several temperatures around a normal value and used in the computations.

* Proceedings of the Institution of Civil Engineers, Dec., 1902.
† This Pitot tube was kindly furnished us by Commander J. C. Hunsaker, U. S. N.

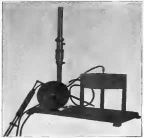


FIG 3. CURTISS ABSOLUTE GAUGE, SHOWING SLIDING RINGS

With the wind off, the slides are adjusted until the meniscus M comes at the center of the glass tube G, and at such a position that a rotation of the disc does not alter the reading. The effect then of giving different inclinations to the disc, and, therefore, of the glass tube, is merely to alter the sensitiveness. By making the angle with the horizontal very small the instrument becomes very sensitive.

One great advantage of this instrument is that as the meniscus is always at M, the effects of changes of bore of tube and capillarity are entirely eliminated. Dr. Hunsaker found these effects to be serious, errors amounting to several per cent being common. The inclined gauge indications are usually too low. He also states that under certain conditions it can be used as an absolute instrument to an accuracy of 1.5 per cent, but that as it is sensitive to less than ¼ per cent changes in velocity it may be calibrated against a better manometer and when calibrated may be as precise as the standard. The Curtiss gauge is an inclined gauge and the "better manometer" combined. As mentioned above, in actual use there is no change of level in the reservoir as no liquid issues therefrom. In addition, by constricting the rubber tube between the reservoir and the glass tube, any amount of damping can be obtained.

The method of use employed at the Curtiss Laboratories is as follows. Wind speeds corresponding to every half-inch of level are computed. The height of the disc is adjusted by means of the plugs and the slow motion screw until the liquid meniscus is at the center. The combination sliding piece H is raised exactly the desired number of half inches without any further use of the micrometer. This height corresponds, of course, to a calculated air speed. The readings of the fixed inclined tube service gauge are taken for these speeds and from these the readings corresponding to 20, 30, 40, m.p.h., etc., are found from a plot. It is, of course, possible to set the standard gauge at a height corresponding exactly to 20 or 30 m. p. h., but the first mentioned is found to be preferable.

The merit of this instrument lies in its simplicity. There is nothing to get out of order, there are no readings as such to be made, the reservoir level does not change, there are no uncertainties due to bore inequalities or capillary corrections, and the instrument is always ready for use. When not in use the end V of the rubber tube DV is placed over the outlet C which prevents all losses by evaporation and consequent changes in density.

The gauge can be adapted for very high wind speeds by employing mercury instead of alcohol or water. The only change required would be in using an iron, glass or steel reservoir instead of brass.

The difference in pressure ($\triangle p$) between the static and dynamic openings of the standard Pitot are related to the speed of the air (V) and the air density (ρ) by the following formula:

$$\triangle p = \tfrac{1}{2}\rho V^2$$

The Curtiss Aeronautical Laboratory has adopted a standard

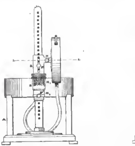


FIG 4. FRONT VIEW OF THE CURTISS ABSOLUTE PRESSURE GAUGE

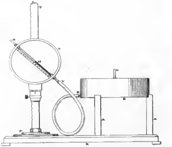


FIG 5. SIDE VIEW OF THE CURTISS ABSOLUTE PRESSURE GAUGE AND DETAIL OF MICROMETER SLIDE

air density of .001223 gm./c.c., which is also in use at the National Physical Laboratory in England, at the Bureau of Standard at Washington and by the Washington Navy Yard. This density corresponds to a value of g of 980.6 c.m./sec.², barometric pressure of 760 m.m. of mercury at 0 deg Cent., air temperature of 15.6 deg. Cent. and 0 per cent. humidity. With this value one inch of water at its temperature of maximum density corresponds to an air speed of 45.146 m. p. h. The following table gives values of air speeds corresponding to various readings on the absolute gauge using a fluid of density 1 gr./c. c.

TABLE SHOWING AIR SPEEDS IN CURTISS TUNNELS CORRESPONDING TO DIFFERENT HEIGHTS OF WATER MANOMETER.

Inches of Water	Standard Air Speed in M. P. H	Inches of Water	Standard Air Speed in M. P. H
.5	31 92	5.5	105 9
1.0	45 146	6.0	110 6
1 5	55.29	6 5	115.1
2.0	63 85	7 0	119.4
2.5	71 38	7 5	123 6
3.0	78 20	8.0	127 7
3.5	84 45	8.5	131 6
4.0	90.29	9 0	135 4
4.5	95 77	9.5	139 1
5.0	100 95	10.0	142 8

If the density changes, either through temperature change or by the employment of a different liquid, these values of air speed are to be multiplied by the square root of the new density referred to water at 4 deg. Cent.

It is hoped that all aerodynamic laboratories will adopt these standard conditions so as to eliminate confusion and make experimental results directly available for comparison.

The accompanying table is of interest at the present time, as it shows the standard air densities adopted by the foremost aerodynamical laboratories. It will be noticed in connection with this table that, although certain variations in standard air temperatures and humidity occur, the values of the standard densities show a maximum variation of but five parts in 1,000. This variation is well within the experimental error of the greater part of aerodynamical work at the present time, so that for all practical purposes results are directly comparable.

It is distinctly encouraging to find that six out of the eleven laboratories here listed are in absolute agreement.

It is to be hoped that all laboratories will see their way clear to adopt the standard air density of .001223 gm./cm.³ In order to obtain the corresponding value, .07635 lb./ft.³, we have used the value of 62.43 as the number of pounds per cubic foot of water.

STANDARD AIR DENSITY USED AT VARIOUS AERODYNAMICAL LABORATORIES

Laboratory	Air Density Metric	English	G	P	Temp Hg	Temp. Air	Hum Air	Authority
Units Used	gms/cm	pds/ft³	cm./sec²	mm Hg	°C	°C	%	
Bureau of Standards Wash., D. C.	.001223	.07635	980 6	760	0	15 6	0	Bureau of Standards
Curtiss Res. Lab. Garden City, L. I.	.001223	.07635	980 6	760	0	15 6	0	Dr J. G. Coffin
Washington Navy Yard, Wash., D. C.	.001223	.07635	980 6	760	0	15 6	0	Com. J. C. Hunsaker
N. P. L. (England) Teddington	.001223	.07635	980 6	760	0	15 6	0	National Ad. Comm. Rep., 1915, p. 38.
Leland Stanford, Leland Stanford Cal.	.001223	.07635	980 6	760	0	15 6	0	E. P. Lesley
Throop College Pasadena, Cal.	.001223	.07635	980 6 / 32 2ft.	760	0	15 6	0	Dr. H. Bateman
McCook Field, Dayton, Ohio	.001222	.07631	981 5	760	0	15 0		Col. T. H. Bane
Langley Field, Va.	.001221	.07625	980 6	760	0	15 0	50	E. P. Warner
Wright, Dayton, Ohio	.001221	.07622	980 6	760	0	16 1	0	Orville Wright
Mass. Institute Tech. Cambridge Mass.	.001219	.07610	980 6	760	0	16 6	0	Smith. Misc. Coll. Vol. 62, No. 4, p. 30.
Eiffel, Auteuil, Paris.	.001226	.07648	980 6	760	0	15 0	0	Eiffel Resis. of the Air p. 18

New Pursuit Ship-Plane Used by the United States Navy

THIS MACHINE TAKES OFF ON ITS WHEELS FROM BOARD SHIP AND ALIGHTS ON THE SEA, WHERE THE AIR BAGS KEEP IT AFLOAT

U. S. Navy Photo, from Kadel & Herbert

Directional Stability and Control of Airships

By Ralph H. Upson

Chief Aeronautical Engineer, Goodyear Tire and Rubber Co.

(Continued from issue of April 1)

There are only two factors that need here to be considered (a) Gusts or erratic movements in the surrounding air, (b) Instability of the airship itself.

Consider the effect of a sudden side gust on an airship previously moving straight through the air. The ship will either turn away from the gust, or toward it, or as a special case will maintain its direction practically independent of the gust. The first case is the natural condition of all elementary shapes and is the one which causes most of our troubles. This instability of direction which causes an initial small deflection to become greater instead of less, we shall first consider without reference to what started it.

Instability is due to the forward position of the center of pressure at various angles of yaw. At small angles this is usually, for an unfinned airship hull, well in advance of the actual nose. It moves back as the angle of yaw is increased. This seemingly paradoxical condition will be readily understood by reference to Fig. 4, which shows the distribution of air pressure around a typical airship shape. The areas showing positive pressure are shaded to indicate which ones are forcing the ship around clockwise and which counter-clockwise. The upper diagram shows the ship headed perfectly straight, in which case all pressure areas are balanced and the ship is in equilibrium.

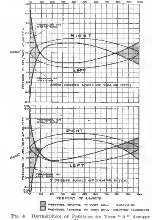


Fig. 4 Distribution of Pressure on Type "A" Airship Hull

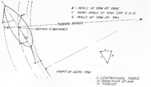


Fig. 5 General Case of an Airship Making a Turn

Consider now the lower diagram representing a condition of 5 deg. yaw. There is a considerable balance of pressure in the front tending to turn the ship clockwise and a considerable balance in the rear also tending to turn it clockwise. The same is true of the negative (unshaded) pressure along the central portion. Thus the ship is not only pushed around by the pressure on the nose, but also pushed around at the tail and pulled around in between.

The net effect of these various components together with the skin friction may be represented by a single force as shown for different angles in Fig. 4. This force intersects the axis of the ship at a point known as the center of pressure. The total force multiplied by its perpendicular distance from the center of buoyancy (or center of gravity) of the ship gives the turning moment.

After an airship which is unstable for straight line motion has once started to turn, it soon becomes stable in a curved path due to the fact that the tail then assumes a greater angle of yaw than the nose and travels at a higher speed. An airship with the usual fixed fin surfaces is in equilibrium on only two forms of flight path: (a) unstable for straight flight, (b) stable for motion on a curve of a certain fixed radius, depending on the shape of bag, size of fins, etc.

The natural flight path of any airship is determined by the conditions which make the total dynamic pressure equal and opposite to the resultant of the thrust and centrifugal force, all three forces intersecting at one point which is usually at the center of gravity of the ship. If from the center of the flight path circle a radial line be drawn perpendicular to the ship's axis it will intersect the axis at a point usually near the nose of the ship. This is the point of tangency or point of zero yaw, which must not be confused with the center of pressure, as mentioned above.

This condition of stable curvilinear flight is shown diagrammatically in Fig. 5.

Requirements for Stability.—The extraneous forces required to produce a stable condition for any desired flight path and particularly for straight flight have now to be considered.

This matter of straight line stability is the only thing that can be properly investigated in a wind tunnel, at least by present accepted methods. Fig. 6 shows a typical case of a bare hull on which must be superimposed the effect of the various fins and control agencies. As will be brought out later this wind tunnel study can be confined to very small angles of yaw (usually under 5 deg.). Stability is affected by the size, shape and speed of the ship, and the size, shape and disposition of the various fins, control surfaces, cars, etc.

As a matter of definition, we will say that an airship itself is a stable one (for rectilinear motion) when it tends always to head straight into whatever air it strikes.

The angular deflections of a stable ship are limited in proportion to the nature of the disturbance, the angular deflection of an unstable ship is unlimited in amount.

We will say that an airship is neutral for any particular form of external disturbance when its axis during the disturbance keeps a position parallel to its original position. A ship which is neutral for some one form of disturbance is not necessarily neutral for other forms. More specifically, neutrality at some definite angle of yaw does not necessarily imply neutrality for other angles.

It should be clear by this time that a strong, positive stability is not the condition desired. We do not want a ship that swings like a weather vane to meet every gust it encounters. Moreover an attempt to even approach this sort of stability by any arrangement of fixed surfaces puts a heavy drag on the ship and makes it much too sluggish to maneuver. It is for this reason that many pilots claim to prefer a strongly unstable ship.

To properly control a ship automatically it should be as near neutral as possible, but slightly stable (for straight flight). To secure this stability with fixed surfaces alone however, involves a large over-stability at larger angles and a huge over-control on various flight path curvatures.

Proper movable surfaces can be adjusted to the exact angle necessary to meet each different condition. A large ratio of movable to fixed surface area is the only way to secure proper stability for straight flight, combined with quick maneuvering ability. Practice in fin design lies more and more toward reducing the fixed surfaces to a condition of being mere structural supports on which to hang the movable surfaces.

This process of meeting the requirements for straight flight and other conditions by a proper setting of movable surfaces, whether manual or automatic, we shall put under the next heading.

Requirements for Control.—We will say that an airship is controllable when, regardless of the magnitude of the disturbing moments, or the deflections produced thereby, it may always be brought back to a condition of rectilinear motion from any other condition of motion.

A ship is exactly controlled on any given flight path, straight or curved, when the control forces tending to rectify the path are just sufficient to hold the ship on it.

A ship is over-controlled on a path of any given radius when there is a surplus control force, which increases the radius of curvature.

A ship is under-controlled on a path of any given radius when the control forces are insufficient to hold that particular radius of curvature.

We will say that an airship is properly controlled when for each radius of flight path it is slightly but definitely over-controlled (always providing that this gives sufficiently quick maneuvering qualities).

Assuming the ship on a straight course, it can be held on this course as long as a righting moment due to the movement of certain controls can be generated soon enough to overcome the disturbing moment. This means that the ship can be controlled at or near a condition of straight flight with an indefinitely small movable surface, providing the external disturbing moments take an indefinitely long time to develop, or if the controls can be moved instantaneously to the correct position.

A control which is capable of holding the ship on a straight course is not necessarily sufficient for bringing it out of a sharp turn. For each ship there is a certain critical radius of curvature of the flight path which requires a maximum deflection of the controls to prevent the ship from going into a still sharper turn. It is this condition which determines the efficiency of the movable surfaces compared to an equal area of fixed surface. This efficiency factor is usually found to lie between 2 and 4.

It is clear that most of these items cannot be handled by any direct method in the ordinary wind tunnel, since there is no way in a tunnel of duplicating the practical conditions of curved flight. More than anything else the situation seems to demand a return to the whirling arm apparatus of Langley, which since his time has been so largely superseded by the wind tunnel. Much also remains to be done in co-ordinating results by careful experiments on full size airships, particularly with respect to the actual form and magnitude of the various air gusts.

Here one may quite properly ask the question, as this sub-

Fig. 6. Vector Diagram of Air Forces on Type "A" Airship Hull

ject is so important for airships, why is it not for water craft, particularly submarines? The answer is unmistakable. A submarine, and to a modified extent an ordinary steamship, is dependent on the same general laws as affect the steering of an airship, but in the matter of degree the cases are quite different.

A boat is a craft of large mass compared to its surface area and travels through a liquid which is practically at rest, except for the periodical wave movements on the surface. Also with the small surfaces and large displacements involved there is no great harm in fitting a considerably oversized rudder to a boat.

An airship has almost the opposite characteristics. In the same time that a boat would be deflected from its course perhaps 1 deg. in 10 sec., an airship might be thrown off her course 30 deg. The fundamental difference then is simply one of time, with the supplementary point that unnecessary weight and resistance are especially important to avoid in airship design. It should not be inferred however, that this subject is of negligible importance in marine engineering. On the contrary, there seems considerable possibility for improving the steering qualities of various water craft.

Systems of Control.—Any competent airship pilot recognizes some or all of the following as aids in steering: Lanes on the ground, waves in the water, stars, clouds or horizon marks, compasses, turn indicators, pennants or weather vanes, rolling or banking of the ship, the air pressure on the rudder as indicated by the pull on the foot bar. But ask a pilot how he actually knows when, in what direction and how far to move his rudder, and nine times out of ten he will not be able to describe it except by a vague sense of judgment or "feel."

Any attempt at improving a system of control, particularly if it be automatic, must be dependent on an exact knowledge of what can be done from a practical standpoint. It happens that all the agencies above mentioned fall into a rather simple classification. This, it should be noted, is for corrective control only and has no reference to position finding or navigation proper, which is an entirely separate subject.

Whether manual or automatic, the corrective control must take its operation or effect from reference to certain outside

conditions with respect to the ship itself. In general these possible reference conditions are based on (a) the distance of the ship from a selected line in space, (b) the angle of the ship compared to a certain geographical direction, (c) the angle of yaw against the air These three forms have variations in degree usually as follows.

A first degree control can only be with respect to the position or distance from the reference line For example, to follow a straight line on the ground without reference to anything but how far you are to one side or the other This is an impossible type of directional control if used alone, on account of the oscillations involved, which increase in a diverging series of values A first degree directional control is almost never used in practice except in starting or landing In ordinary flying if the ship gets too far off its linear course, the course is simply altered to correspond

A second degree control may be either with respect to the movement from or toward a given line or the angle in which the ship is headed This type of control always "hunts" but is necessary in some degree to hold a given course The oscillations are usually large but tend toward a certain fixed amplitude as a limit A good illustration of a second degree control was the attempted use of a gyroscope as mentioned in the first part of this paper

A third degree control may be with respect to acceleration referred to a line or angular velocity or angle of yaw (which also determines the radius of the flight path circle) This must be the predominating feature of any practical control system Under this type of control also, the ship usually oscillates, but in a converging series. The direction is indeterminate Another way of describing this control is to say that it always opposes the angular motion with a force which is directly proportional to the angular velocity. It is merely a damping control, without any reference to the actual deflections involved

A fourth degree control may be based either on angular acceleration or the rate of change in the angle of yaw This is the only way of stopping the effect of a disturbance at its source The flight path in this case is of smooth but indeterminate shape It is almost impossible for a human pilot to accomplish this method of control to any practical extent because he is not situated where he can judge the variations accurately enough

The best he can do is go by the "feel" of the rudder or by watching the angle of a streamer There are certain types of automatic control which will take care of it fairly well. The neutralizer vane, previously described, usually acts as a sensitive third degree control, but in respect to disturbing gusts from the outside it is more properly a fourth degree control since when correctly designed it reacts in similar proportions to the disturbing force itself

The following table shows graphically the usual relation of the various classes and degrees of control — (See also Fig 7)

	Line	*Direction*	*Yaw*
1st Deg	Position		
2nd Deg	Movement	Angle	
3rd Deg.	Acceleration	Angular Vel	Angle of yaw
4th Deg		Angular Accel	Change in angle of yaw

This arrangement is based on the assumption that the angle of yaw is referred to still or uniform air conditions. Where a momentary angle of yaw is due to an outside air gust it may be utilized directly for fourth degree controls, as in the example just given

The design and operation of a practical control system are further influenced by the necessity of meeting various incidental requirements which must next be considered

The most important thing to be mentioned here is the effect of the ship's mass and moment of inertia These retard the motion produced by any new set of outside conditions and continue the effect beyond the position where a given motion would otherwise be stopped The former effect only involves an element of time The latter produces the slight oscillations typical of third degree control as already mentioned In general a large moment of inertia, compared to the ship's effective surface area, is a steadying factor mainly because it slows down the movements, and gives more time for effective and accurate control Also when the moment of inertia is large compared to individual disturbances it tends to smooth them over so that they partially counteract each other

Owing to the structural requirements this factor cannot be much changed or adjusted in any one size and type of airship As between different sizes however, the larger ones clearly have the advantage in their larger proportional mass and the fact that the load is not usually so much concentrated under the center as it is in small ships

The propellers have an effect that must now be considered. Multiple propellers not directly under the ship obviously exert a turning moment when one or more of them are throttled or stopped The effect is so slight however, compared to the other forces we have been considering that under ordinary conditions it can hardly be noticed, much less utilized as a means of steering It is only with very steady air conditions or with an efficient automatic control that it is much of a factor In the latter case it is a cause for adjustment of the controls a little off of neutral

The effect due to the twist in the propeller slip stream is somewhat more serious A fin or control surface in the wake of a propeller (especially a pusher type) sometimes has to

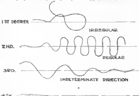


Fig. 7 Typical Paths Corresponding to Different Degrees of Control

be set at a considerable angle to preserve a neutral condition This works well for a straight flight, but when the radius of the flight path circle gets less than a certain amount the slip stream misses the fin entirely and radically changes the conditions surrounding it Also the angular setting of a fin is clearly unsuited to towing or mooring in a wind These troubles may be cut to a minimum by increasing the ratio of movable to fixed surface The best arrangement for twin propellers is side by side, both turning inward on top

Some form of power control (not necessarily automatic) is an almost necessary development for large airships, for the same reason that it is found necessary on large steamships In the case of an automatic control the problem is easily solved by utilizing for manual or forced control the same source of power that is most convenient for automatic operation, namely the power of the relative wind

The size and shape of fins and control surfaces bring in several practical aspects other than that of actually controlling the ship It goes without saying that the resistance and weight must be kept down to a minimum consistent with adequate strength. We also want to keep the side resistance as low as possible to reduce the difficulty of handling the ship on the ground The necessary stabilizing effect can be obtained with the least surface by using surfaces of large aspect ratio, i e long in a direction perpendicular to the axis of the ship Various structural limitations however make it almost impossible to accomplish this to any great extent

In the first place the surfaces must be quite rigidly braced to the envelope and this bracing becomes exceedingly difficult on a fin which projects more than about half the diameter of the envelope at the point where it is attached Also the strain at the base of the fin must be spread over a considerable area of the envelope, which usually involves a certain minimum base length. Then to get maximum hangar and ground clearance it is unwise to let the fins project much beyond

Fig. 8 Goodyear Type "A" Pony Blimp

the maximum diameter of the envelope The Italians settle some of these difficulties by concentrating all their control surfaces into a cellular structure under the envelope. (See Fig 1.) This arrangement has considerable resistance and with a long ship would give insufficient ground clearance, nevertheless the system is deserving of very serious study

On most ships it is found advisable to have at least part of the vertical stabilizing surface on top of the envelope. This is because it is more effective in preventing rolling and because the lower surface is sometimes partly blanketed by the envelope when nosing down And there is usually a limit to the amount of surface that can be put underneath, and the balance has to be put on top An extreme case of this is the Zeppelin construction In this as in the general case it is more efficient the greater the percentage of movable surface But in small non-rigid ships, mechanical simplicity usually demands a plain fixed fin on top. (See Fig 8.)

A non-rigid airship even when up to pressure is quite flexible under the various wind forces. This not only changes the conditions of flow somewhat, but also disturbs the setting of the controls themselves by tightening certain wires and loosening others. There are three methods of meeting this condition (a) Gear the control cables up so that they move a long distance for a comparatively small movement of the rudders. (b) Arrange the cables so that a distortion of the ship will pull the rudders in a direction to correct for the original disturbance. (c) Put a self-locking device on the rudder and leave the control cables slack or the control wheel loose.

Goodyear Type AA Pony Blimp

The second Pony Blimp, Type AA, which, like the first, is 35,000 cu. ft. in capacity, is almost completed, ready for trial flights. This unit is slightly different from the Type A ship, the main change being that the car is designed to accommodate a tractor type motor.

General Structural Information.—Wherever possible, wooden construction is used throughout, thereby giving a light but strong car, capable of rough handling, such as is sometimes encountered during a landing The car skeleton is made up of four longerons, fastened to veneer bulkheads by metal clips. The side and bottom are of thin veneer, which gives additional strength as well as protection The cowling is made of sheet aluminum, covering the front and rear sections The front cowl is high enough to protect the pilot from the propeller air blast and oil thrown back by propeller blast. The car body is rectangular in cross sections, being streamlined as near as possible. A single skid landing gear takes the front suspension, and in order to prevent shock when landing, a pneumatic pontoon is fastened on the bottom of this skid. The length of the car is 10 ft. 6 in., the maximum width 32 in. Weight, in running order, with the exception of the fuel, is approximately 490 lb

Power Plant—The motor used is a Lawrence, 3-cyl., air cooled, radial type, developing 50 hp. at 1,500 r.p.m., and driving a tractor screw.

Provision has been made for cranking this motor by mounting the crank directly within reach of the pilot, thereby enabling him to have complete control over the ship, which is a decided advantage for a tractor type ship over the pusher type when motor is not equipped with electric starter

The three cylinders are connected together by an exhaust pipe which leads into a single outlet. A muffler will be provided on the end to cut down the noise. Care has been taken to protect the motor from fire. A fire wall separating the motor from the pilot and an automatic fire extinguisher is connected directly to the carburetor.

Gasoline System.—The total fuel capacity of 40 gal is carried in the car. This capacity gives a duration of flight, at full speed, of 10 hr. or 20 hr. for cruising speed. One main tank of 35 gal. is mounted in the rear section and the balance of 5 gal carried in a gravity tank

The gravity tank is fed from the rear tank by means of the standard Stewart vacuum system, this being mounted directly into the gravity tank. A hand vacuum pump is also supplied to be used in case the Stewart system should ever fail. This gravity tank has a separate compartment for 3 gal. of reserve oil, which feeds through the engine pump by merely opening a valve.

Due to having such a large gasoline capacity for as small a ship, it is desirable to take advantage of this fuel as emergency ballast. Therefore, an amply large discharge valve of standard Goodyear type is located on the main tank.

Controls—The elevator and rudder controls and cable are mounted on the inside of the car, coming out of the car at the rear The elevators are controlled by a wheel mounted on the right hand side, and the rudder is controlled by stirrups.

Special snaps are located on the ends of the control cables to permit quick assembly and dismantling of the ship.

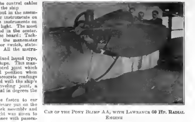
Instrument Board.—The main idea carried out in the assembly of the instruments is to have all the motor instruments on the left hand side of the board and the balloon instruments on the right hand side, lighting all by one electric light. The most needed instrument, the manometer, is mounted in the center. The following instruments are mounted on the board: Tachometer, manometer (by special arrangement the manometer also serves as an inclinometer), aneroid, motor switch, statoscope, oil pressure and temperature gauges. All the instruments are radium lighted.

The manometer mentioned above is of standard liquid type, the same as previously used in all Goodyear ships. This manometer has been specially mounted on a pivoted joint which serves to keep the manometer in a vertical position when ascending or descending, thereby giving more accurate readings than can be obtained if the manometer inclined with the ship's inclination. To take advantage of the swiveling joint, a pointer is also attached which indicates on a dial in degrees the amount of inclination.

Suspension.—Where cable suspension clips fasten to car they can be easily removed by taking out a clevice pin on the outside. The idea is to have a means for quick assembly and dismantling of the ship. Considerable thought was given to this suspension so as not to have any interference with passengers getting into or out of the cockpit.

Top.—For protection in cold weather a light top is mounted over the cockpit. A triplex glass wind shield is used to enable the pilot to have a clear vision. The side curtains are so constructed that they immediately open by means of a rubber elastic upon pulling a single latch. This enables passengers to get out of the car very quickly in case of emergency. The top is readily detached from the car body when not needed.

Parachutes.—Two containers are built into the inside of the car and under the rear seat; they open through the bottom of the car. A parachute pack is placed in each of these containers and is held in place by a door closing the outlet. This pack is fastened to the car by two cables 6 ft. long, so that when the parachute is needed the pack will fall clear of the car before chute leaves the pack.



Car of the Pony Blimp AA, with Lawrance 60 Hp. Radial Engine

Drag Rope.—Seventy-five feet of 5/8-in. rope is located under the pilot's seat in a suitable container. This drag rope can be released when needed by means of a trap door on the bottom of the car. When released for use, one end of the rope is fastened to the front skid and a bridle is formed by cable connection to the bag. This arrangement permits easy towing or holding of the ship.

Seats.—Two seats are provided to ordinarily accommodate two passengers. The rear seat is, however, sufficiently spacious for two passengers, if desired. The seats are built of slats and upholstered bottom and back, making a comfortable seat for long flights. The pilot's space, including the seat, is very roomy.

Internal Arrangement of the New Car of the Pony Blimp, Looking Forward

Engineering Division Has New Test Furnace

The Material Section, Engineering Division, Air Service, is supervising a test of the Government furnace at Shelby, Ohio. This furnace was installed during the war for the purpose of heat treating steel tubing in quantities for airplane construction but was not completed until recently. It is now completed and undergoing a series of tests to determine the feasibility of producing heat-treating steel seamless tubing of very high tensile strength and elastic limit, to particularly meet Air Service Specification No. 10,229, for axle tubing.

The furnace, located at the plant of the Ohio Seamless Tube Co., is 7 ft. in diameter and 22 ft. deep, electrically heated and automatically controlled so as to give constant temperature within very narrow limits. The tubing is lowered into the furnace, which is sunken so that the top of the furnace is level with the floor, in a steel container (capacity 1152 ft. of 2-in. tubing) by means of a crane. On reaching the required heat the container with its cargo is hoisted out of the furnace, transported over the quenching tank where the bottom of the container is opened and the steel tubing, at the quenching temperature, is allowed to drop into the oil quenching bath.

The tempering operation is conducted in a similar manner, except that the maximum temperature of the tubing in the furnace is, of course, lower than it was for the quenching operation. These tempers run approximately 1400 deg. to 1600 deg. Fahr. for the quenching operation and 400 deg. to 1000 deg. for the tempering operation, depending on the quality of steel used and the physical characteristics desired.

This furnace will be used principally for the heat-treating of alloy steel tubing with special reference to the tubing used in axles. Up to the present time no axle tubing has been produced in quantities which will meet the requirements of Specification No. 10,229 calling for 200,000 lb. tensile strength with 5 per cent elongation in two inches.

The Gourdou-Leseurre Pursuit Airplane

By Charles Gourdou *

General Fundamentals of the Problem.—We wished to build a fast monoplane armed with two machine guns and powered by a Hispano-Suiza 180 hp. engine. We determined on this construction for the following reasons:

The efficiency of the monoplane is superior to that of the biplane. The engine chosen gave every satisfaction. Also, examination of the performances of the Spad with 180 hp. Hispano-Suiza engine and their close agreement with laboratory tests showed us that it was possible to greatly exceed the results obtained with this machine without increasing the power of the engine. The Spad was a very remarkable machine for the period in which it was built; it has, however, had its day. Its wood construction was within the capabilities of a large number of factories in the Paris region, but when it commenced to appear a little slow and when the Technical Section was forced to the use of engines of greater and greater power it appeared to us clearly that the risks to be run in constructing a new airplane furnished with a new engine were not counterbalanced by the hope of obtaining sensational results.

Experience has confirmed our predictions, since the performances obtained with our airplane are comparable to those of new machines having engines of 300 hp.

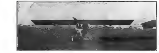
The choice of the engine and monoplane construction being determined, we also wished to make an extremely strong metal machine. Numerous accidents with monoplanes have shown that the low total resistance of these airplanes should correspond to very great strength. Let us assume that the pilot dives his machine so that it reaches its limiting speed. The force of gravity is then the engine of the airplane, and in a vertical dive the speed increases until the resistance of the air on the wings, fuselage and propeller counterbalances the action of gravity. The speed reached thus depends essentially upon the resistance of the machine. Measurements made in the laboratory on a scale model of our machine and comparisons with existing machines caused us to predict a diving velocity of about 250 m. p. h. If the pilot rights the machine very quickly when the greatest speed is reached the wings will be highly loaded. We have assumed that the machine can be righted in one second; in practice, however, the length of time is somewhat greater. Under these conditions it is easily proved that the wings support a load about fourteen times the normal load. Thus, it is easy to explain, apart from defects in construction, the frequency of accidents on monoplanes, the low total resistance of which permitted speeds in the neighborhood of 220 m. p. h. and the parts of which could not withstand loads greater than five times the normal load. At the beginning of the war the factor 5 was believed by the Technical Section to be ample.

We considered it necessary to design the parts of our machine so that, when they were stressed to their maximum, the elastic limit of the metals employed should not be reached or at least should not be exceeded. We, therefore, prescribed for ourselves the condition of having the metals stressed in the neighborhood of their elastic limit when the machine supports fourteen times its normal load. It is understood that all the parts of the machine should in general be calculated with the same coefficient.

Choice of the Dimensions of the Machine.—The armament and the weight of fuel to be carried for two and one-half hours flight, and comparison with existing machines made us anticipate a weight of 1,848 lb.

As the loading of 9.2 lb. per sq. ft. did not appear excessive for a monoplane we chose an area of 200 sq. ft. To attain this area in a monoplane without giving it excessive span (which would have increased constructional difficulties) we adopted a wing of 30.8 ft. span and 6.56 ft. chord. The aspect ratio (4.7) of such a wing may appear small, but strength considerations made it necessary for us not to exceed limited dimensions for the span.

Choice of the General Arrangement of Trussing.—Deformation of the wing surfaces under load is to be avoided as it reduces the efficiency and stability of the machine. A rigid machine cannot be made if cables and piano wires are used in its construction as principal supports of the wing structure, their stretching in service being too great. Also, cables and wires can be used only in tension, and cable trussing should be doubled so that the wing will withstand top loads when flying up-side down and stunting. We, therefore, decided to employ for wing supports struts composed of steel tubes. This trussing arrangement, as shown in the front view of the machine, is also excellent in that it has a low head resistance; also, the air pressure is low on the top of the wing, therefore, by virtue of a well-known theorem, the air speed is greater above the wing than below, and the resistance of parts placed below the wing is less than if placed above it.



Front View

Side View

Each of the wing spars is attached at five points to the rigid trussing which connects the wings to the fuselage. We have chosen the positions of the points of attachment on the spars so that the bending moments are equal at each of the points of attachment. When the wing is loaded, it is obvious that the spars are under bending stress by the action of the loads and under compression by reason of the reactions of the oblique struts. Computation shows that the bending moments at the point of attachment of the struts are equal if the bays are approximately equal, and that they increase starting from the axis of the wing. The bays would be obviously equal if the compression due to the angularity of the struts is not taken into account.

The points of attachment of the struts thus chosen, the bending of the spars in each bay will be symmetrical with respect to the center of these bays. Variation in the angles of the struts and the spars will be due only to the elongation of the struts under load and to shortening of the spars. Variations of length in these parts are exceedingly slight, and we may consider the angles as constant, and consequently make the attachments rigid. The attachment of the spars to the wings is formed of soft steel fittings which are bent so as to completely surround the spar; the strut is attached to the fittings by two large hollow bolts giving ample bearing surface.

The struts are connected to the fuselage by long threaded sleeves which permit adjusting the wing. It is obvious that the trussing system is thus composed of triangles insuring perfect rigidity. Finally, the centres of the outer struts are connected by small struts to the points of attachment of the inner struts so that the former will withstand the load of flying upside down with a sufficient factor (12 has been chosen).

* Translated from the French by John Jay Ide, Lieut. (j.g.) U.S.N.R.F.

THREE-QUARTER FRONT VIEW

The Fuselage—Four tubular longerons (the upper longerons of steel, the lower of duralumin) constitute the framework of the fuselage. As we must first of all connect the wings to the fuselage by struts and cabane tubes, we must find out which are the best points on the fuselage to attach the struts.

Let us consider a side view of the airplane: the struts, both large and small, are in the plane which passes through one of the wing spars and one of the points of attachment on the fuselage. We see that the planes of the fore and aft struts form a slight V, the apex of which is directed upward. This arrangement is chosen for the following reasons. We desire to balance the drift stresses on the wing by the trussing (at least in normal flight) independently of the interior cross-bracing of the wing. The planes of the two fore and aft sets of struts when prolonged cut each other on a straight line parallel to the wing spars. In Fig. 5 this straight line is projected to the point of intersection of the two lines of the struts. The resultant of the air forces on the wing, which is slightly inclined from the perpendicular of the wing chord, runs from a point 30/100 of the distance from the leading edge and passes through the point of intersection of the axes of the trusses.

As there are several convenient methods of attaining the desired balance we can prescribe one more condition. Let us consider what happens when the wing is in flight. It is evident that the wing tends to move slightly aft under the load which it supports. We have, therefore, chosen the position of the strut attachments so that, if this movement aft takes place, the angle of incidence of the wing is decreased, thereby reducing the lift. This leads to a digression on the question of the stability of airplanes in flight.

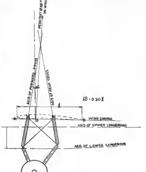
To be understood better, let us consider the flight of a machine the deformations in flight of which are fairly great. This would be the case for example in a monoplane of large span with cable trussing or in a biplane with large bays without drift cables. The wing moves aft under the force of the load. If the angle of incidence increases in this movement aft the machine will tend to be unstable. Thus in a turn, for example, the upper wing having greater speed will move farther aft and the angle of incidence will tend to increase, which is contrary to the movement of the controls by the pilot. Even in normal flight if one of the two wings is loaded more than the other from any cause its deformation is such that the load tends to increase. If, on the contrary, the deformation decreases the angle of incidence, the movement aft tends to return the wing to normal conditions. The directional instability of certain machines can be attributed to these deformations which slightly alter the conditions under which the wing operates.

REAR VIEW

Having thus determined the main points which should guide us in the construction of the fuselage, we must now examine the construction of the engine support and the arrangement of the pilot's cockpit. The center of gravity determination diagrams in conjunction with visibility requirements fixes the position to give to the center of gravity of the engine and to the pilot's seat. These points being decided, let us examine some general conditions which should guide us in designing the engine support.

Engine Support—The various parts of the engine should be accessible and disassembling the motor should be easy. We must therefore simplify the constructional parts and reduce their number. The engine support should also be able to support the considerable loads which we will now analyze.

In flight the engine is supported by the forward part of the fuselage. The points of attachment of this portion are



JUNCTION OF THE WINGS TO THE FUSELAGE
DIAGRAM OF THE MAIN POINTS OF ATTACHMENT

the points of attachment of the wings to the fuselage. On the ground and in landing the engine is supported by the fuselage which rests on the landing gear. Finally, the engine support should resist the engine torque with a fairly high factor of safety comparable to that of the entire airplane. The factor 6 seems sufficient.

It is not necessary here to enter into the details of the calculations to be made in order to design a proper support. In flight we have seen that the maximum acceleration of the airplane makes necessary a load factor of the wings of fourteen times the normal load. If we carry the fuselage at the proper points the support should be capable of withstanding fourteen times the load of the engine. For the required strength for landing we must consider the height of fall admitted (1.6 ft. for instance) and the play of the shock absorbers and tires, we can then easily deduce the loads which will be brought to bear on the engine support. We have de-

signed this support by using two duralumin cradles attached to the fuselage longerons by special fittings and cross braced by struts. This arrangement with variations has been adopted by a number of constructors.

Center Portion of Fuselage, Pilot's Cockpit—The fuselage is composed diagrammatically of a certain number of vertical frames connected by longerons. In order that the fuselage can resist torsion, it is necessary to cross brace the frames. Now it is evident that it will be difficult to place cross bracing in the pilot's position; in the majority of existing airplanes this cross bracing is omitted. We have preferred placing the pilot in a duralumin circle which strongly braces the first frame. During torsion tests the fuselage of the Gourdou airplane has withstood torsion produced by a load equal to seven times the normal load on the rear vertical surfaces. This load was placed at the center of pressure of the above mentioned surfaces. (It is assumed that the vertical surfaces can withstand the same unit load as the wings.)

We will not describe in detail the manner in which the tail surfaces, landing gear and skid are constructed; we will limit ourselves to stating that we have observed the following precautions in executing our designs:

The bends of the fittings have been arranged so that the welding is never directly stressed. The attachments of cables or wires traverse or encircle the parts to which they are secured.

In an assembly by bolts or pins their sections are such that they can resist shearing stresses, also their perimeter is sufficient for the metal not to be crushed by shocks or vibrations.

We have measured by means of a frequency meter with vibrating blades the vibrations peculiar to the longer parts of the machine, in particular the struts, and have proved that the rates of vibrations do not correspond to the number of revolutions of the engine at speeds that are employed.

Finally, we have insulated the skid support from the parts carrying the tail surfaces so that an accident to the skid on taking off cannot endanger safety in flight.

Characteristics—Careful adherence to these principles and methods the importance of which in modern aeronautical construction of today is becoming increasingly evident led us to design an airplane, the characteristics of which are as follows:

	Ft.
Span	30.8
Length	21.1
Height	7.8
	Sq. Ft.
Wing area	202.3
Aileron area	28.7
Elevator area	14.0
Stabilizer area	13.8
Rudder area	6.7
Fin area	3.4
	Lb.
Useful load	374
Weight of fuel and oil	220
Weight empty	1254
Total weight in flying order	1848

Factor of safety exceeding 22. (Static tests have been carried up to this load, the deformations measured for the load 14 being equal to the calculated deformations).

Factor of safety under top load	12
Rigid landing gear withstanding a fall of	10 in.
Elastic landing gear withstanding a fall of	24 in.
Speed at ground level	150 m.p.h.
Speed at 16,400 ft.	137 m.p.h.
Climb to 9840 ft.	7 m. 30 s.
Climb to 16,400 ft.	17 m. 30 s.
Ceiling	24,600 ft.

Monel Metal for Engine Valves *

The present day aviation engine operates at much higher temperatures than were considered possible a few years ago. One of the greatest problems in the development of such engines has been the securing of a suitable material out of which to construct the valves. The life of ordinary valves is so short and their service so unsatisfactory that an improved material is urgently needed.

In a recent paper presented to the English Institution of Automobile Engineers, the merits of different steels for this service are discussed. No mention is made, however, of monel metal, a material which recent tests at this Bureau indicate to be deserving of serious consideration for this class of work.

Exhaust valves of this material have given satisfactory performance in a 180 h.p. Hispano-Suiza engine during 130 hr. of running time. Of this time, the first 90 hr. were devoted to tests made primarily to study the behavior of the lubricating oils. The engine was operated for periods of about 6 hr. each during which time it was developing between 130 and 140 hp. at 1,800 r.p.m.

Examination of these valves at the end of 45 hr. showed them to be badly pitted, they were ground just enough to reveal the condition of the valve seats and these, too, were found in the same condition, although no considerable drop in power had been noted. During the next 45 hr., the horsepower was substantially the same as during the first 45 hr., although a slight increase appeared during the first run following the replacement of the valves. The valves were then subjected to 40 hr. service under conditions far more severe than those encountered in normal operation. The engine was being used in connection with a study of pre-ignition and for this purpose was operated at 1,800 r.p.m. under full load for a period of from 4 to 20 min. During the greater number of those runs, pre-ignition was intentionally produced resulting in extremely high engine temperatures. An evidence of these high temperatures was furnished in one instance by the fusing of the nichrome electrode of a specially prepared spark plug, the electrode's melting point being 1,500 deg. Cent.

In fact, one of the evidences of pre-ignition was that when the engine was shut down the exhaust valve in a cylinder that had been preigniting would remain red for nearly a minute after the valves in the other cylinders had become black. In spite of the severity of these tests, there was no evidence of power drop from leaky valves. At the end of 150 hr. of running time, the condition of the valves and valve seats appeared to be no worse than at the end of the first 45 hr.

* From Technical News Bulletin No. 33, Bureau of Standards.

Propeller Theory and Design

A series of notes on Propeller Theory, Design and Construction by Alexander Klemin, Technical Editor AVIATION AND AERONAUTICAL ENGINEERING, Consulting Engineer Aerial Mail Service, Consulting Aeronautical Engineer, will be published at frequent intervals in the forthcoming issues of this publication. These notes will constitute a complete study of the propeller, as the title, "Theory, Design and Construction," implies. They will cover this important branch of airplane work in as thorough and systematic a manner as Mr. Klemin's Course in Aerodynamics and Airplane Design covered airplane work in its more generalized aspects. The presentation of these notes at frequent but not stated intervals will enable Mr. Klemin to make each note a complete monograph of the particular aspect of propeller work treated in each note. It is suggested that careful collection of these notes would repay the readers of AVIATION AND AERONAUTICAL ENGINEERING. To indicate the scope of the notes a little more fully, some of the titles of these notes may be given: "Propellers in Tandem," "General Review of Propeller Theory," "Wing Sections Suitable for Propeller Design," "Stress Calculations for Propellers," "Propeller and Engine," "The Theory of the Variable Pitch Propeller," "Propeller Construction," "Propeller Testing."

A series of notes by the same writer will also appear at intervals under the general title of "Notes on Aerodynamics and Airplane Design." These will in some cases extend the subject matter of the "Course in Aerodynamics and Airplane Design" previously published in our columns. In some cases entirely new ground will be broken, while in others a more modern and complete treatment will be given to subjects already dealt with in the course. Here again each note will form a complete monograph of the subject dealt with. Some of the titles will be "Present Status of Stress Analysis," "The Theory of Least Work Applied to Aeronautics," "Materials in Airplane Construction," "Altitude Flight," "Practical Wing Construction."

While in both the notes on Propeller Theory Design and Construction and in the notes on Aerodynamics and Airplane Design, a great many references will be made to the most modern publications, these notes will embody a considerable amount of original study and research, and in many cases will carry the subject further than existing literature on the subject presents it.

The Bureau of Standards Method of Altitude Computation

By Lester D. Seymour

There has been so much discussion of late relative to the various altitude records said to have been made by various pilots, and in connection with these discussions there is always arising the question of how the figure given out as the altitude obtained was arrived at, that while it is neither the writer's purpose to be minutely technical nor to cover in detail the whole matter of calibration and correction, it will be attempted in this article to show the general method of computation employed by the Bureau of Standards and the data on which these computations are based.

The reason for referring altitude records to the Bureau of Standards, is that in so far as the United States is concerned the Bureau of Standards is an official, disinterested, technical office, qualified in equipment and personnel to say exactly what figure is represented by the readings of the instruments carried during the flight in question. It is the logical place for the calibration, etc., to be carried on, because as a Government institution its services are available to the public and commercial concerns as to Government departments.

In order that, in years to come, when methods of determining the altitude, to which any aircraft has carried a particular instrument, may have changed (as they have frequently in the past), it is most necessary that such data be recorded as will make it possible to compute the altitude by any method, then in favor. This statement means to say that there should be collected at the time of the flight all of the information which could possibly have any reflection upon the conditions obtaining during the flight. If this has been done, no matter what method is considered, there will always be sufficient data to compute the altitude by that method, and so by the new method compare old altitude records.

In direct relation to the preceding paragraph is the matter of comparison of altitude records. It should be noted that since altitude records, as indicated by the instruments carried during the flight, may be calculated by various methods, that method by which any particular figure was reached is as important as the figure itself. For this reason, before it can be said that any one man has the altitude record, it must first be said that his altitude has been compared to the altitude of others obtained by the same method of calculation.

The data that should be recorded, beginning, during, and at the end of an attempt to make an altitude record, is as follows: Ground pressure read from a mercurial barometer corrected for temperature, the ground temperature and the air temperature gradient, i. e., the temperature encountered at intervals during the flight. Preferably the intervals should be regular, but this is not essential. Instrument temperature, at ground, and ceiling, and pressure at ceiling must be recorded. The barograph will give the pressures and should be set at ground pressure at the beginning of the flight.

In the preceding paragraph the reason for the instrument temperature at the ground and ceiling may be said to be: Because the temperature will differ considerably in the instrument case within the cockpit and the surrounding air at high altitudes. To avoid this at the ground, the temperature of the instruments can be made almost exactly the same as that of the atmosphere by taking care to leave the instrument in position in the cockpit of the ship for a short time previous to the flight. The air temperature gradient is observed because it is from this that the much discussed correction for the temperature of the air column is made.

Having obtained all of the readings mentioned above relating to a particular altitude flight, the Bureau of Standards observes the following method in calculating the probable altitude reached.

BUREAU OF STANDARDS METHOD

	Inches
Ground pressure in inches of mercury from barograph	
Applying instrument correction for ground temperature	
(a) Corrected barograph reading at ground	
Ceiling pressure in inches of mercury from barograph	
Applying instrument correction for ceiling temperature	
(b) Corrected barograph reading at ceiling	

Then

(c) = a — b, which is the true difference in pressure.

Add the true difference in pressure to the mercurial barometer reading at ground and the true ceiling pressure will be found.

From the tables given in Bureau of Standards' Aeronautic Instruments Circular No. 3, the altitude corresponding to the true ceiling pressure may be found. The next computation is shown below.

	Inches
Altitude corresponding to true ceiling pressure	
Minus altitude corresponding to true ground pressure	

This gives then the isothermal difference in altitude.

At this point a correction must be applied for the varying temperature of the air column between the ground and the ceiling. This correction is necessary because the tables given in the Bureau of Standards Circular No. 3 are calculated for an assumed constant temperature. This correction is made by means of the mean temperature of air column. This mean temperature is the arithmetical mean found from the temperature gradient, which has been mentioned. Practically, the mean temperature may be found by the use of a planimeter and graphic method or mathematically. Having arrived at the most probable figure for the mean temperature of the air column, the correction that must be applied to the altitude indicated in the Bureau of Standards tables as corresponding to the ceiling pressure may be found from tables in the same circular. Now the probable altitude above sea level to which the airplane climbed will be given by subtracting this air column correction from the isothermal difference in altitude, and adding or subtracting true (U. S. G. S.) elevation of the field.

In conclusion it may be said that, undoubtedly, the difference in opinion as to how altitude records should be computed exists almost entirely in regard to that correction which has been taken up in the previous paragraph. This is true for several reasons: First, the correction itself is usually a very large one and reduces the indicated altitude materially. Second, the error due to the difference in temperature of the air column is sometimes calculated without actually realizing it as such, because it is included in an arbitrary formula, which has been used. In either case, there is a difference of opinion as to how the mean temperature correction for the air column should be applied. It is interesting to note that the difference in opinion arose recently from a misunderstanding of methods, e. g., the Bureau of Standards once employed the correction for temperature of air column based upon what was called the harmonic mean temperature, whereas they now base their correction on an arithmetical mean temperature.

That the two are practically the same may be seen when it is considered that the harmonic mean temperature is based upon pressure intervals, while the arithmetical mean temperature is referred to altitude intervals. Engineers who contend that a correction should be made for each small interval in altitude and then go from that altitude to the one next above it, applying another correction and adding, are simply applying the same correction in small increments that is applied in one operation by the other method. However the Bureau of Standards has adopted the method outlined above, and is prepared to calibrate instruments both before and after flight tests for anyone who cares to make attempts at altitude records, and as the official authority in the United States it is believed that their announced "probable altitudes" as calculated by the method outlined above is as close to the true altitude as it is possible to come.

Such matters as the detailed description of the method employed in the calibration of instruments, and the various operations connected with the examination of instruments used during flight tests, while very important and necessary to the selection of the most probable altitudes, are too complex, technical and lengthy for presentation here. In contemplation of the subject, however, the fact should not be overlooked that the instruments themselves, their characteristics and the experiments and tests necessary to find out these characteristics, are as important and have as great a bearing upon the altitude reached, as any part of the computation from the readings, that these instruments give.

Landing Run and Get-Away for Standard Airplanes*

By Alexander Klemin

Association with the air mail service leads me to the conclusion that the length of the landing run constitutes one of the greatest practical airplane problems, particularly when using the fields now available. A fast, heavily loaded machine has excellencies of its own but is not likely to be capable of a short run, a powerfully-acting tail-skid, while giving full braking effect, is likely to damage a field and at the same time impose undue stresses upon the fuselage. In the case of forced landings, it is particularly important to have as short a landing run as possible. The mechanics of the airplane in the air have been exhaustively studied, but no mathematical considerations or conclusions are available concerning landing runs.

Considering the case of a three-point landing, with the engine shut off, in which the pilot flattens out after a dive, places his machine in a stalling attitude and gradually loses speed,

FIG. 1

until the wheels and the skid touch the ground simultaneously. The machine then slows down under the combined action of the aerodynamic and tractive resistances. During taxiing with the machine retaining the same attitude, the aerodynamic resistance is proportional to the square of the speed. The tractive resistance is proportional to the reaction of the ground, this being proportional to the weight of the plane minus the remaining lift due to the wings.

The equation of motion then becomes

$$\frac{W}{g}\int\frac{d^2x}{dt^2} = -c_1v^2 - c_3\,(W - c_2v^2),\ \text{where}$$

x = the distance, measured from the landing point
W = the weight of the airplane in pounds
g = acceleration due to gravity
d = differential
t = the time in seconds
v = the velocity at any point
c_1 = a constant defining the aerodynamic resistance
c_2 = a constant defining the aerodynamic lift
c_3 = the tractive coefficient

Writing $\frac{c_2}{c_1} = \frac{L}{D} = \frac{\text{lift}}{\text{drift}}$ at taxiing attitude, the expression for length of landing run becomes

$$x_1 = \frac{(L/D)\,V_1^2}{2g[1-(L/D)c_3]}\log_e\left\{\frac{1}{(L/D)c_3}\right\}$$

This expression clearly gives an idea as to what extent well-known factors enter in determining the length of run, and shows that this length will be longest if L/D and V_1^2 are large while c_3 is small. It also provides us with a formula from which, knowing the tractive resistance and the aerodynamic properties of the machine, the length of landing run can be determined at once. At present there appears to be little experimental data available for the verification of the above formula under conditions of service.

On May 23, 1919, a comparative test was conducted by the Air Mail Service on the Curtiss R-4-L and the Curtiss HA mail machines at Roosevelt Field, which has well-sodded ground and was in good, dry condition at the time of the test.

Data on the two machines are given in the accompanying table.

Machine	HA	R-4-L
Test load, lb	4,018	4,200
Engine	Curtiss K-12	Liberty-12
Rated power, hp	400	400
Wing area, sq ft	490.0	504.9
Wing section	Sloane	R.A.F. 6
Angle of incidence of wings to propeller thrust, deg	0	2.5
Landing angle, deg	18	14
Ky at landing angle	0.00246	0.00316
Landing speed, m. p. h	56.5	52.0
Wing resistance, lb	1,140	462
Parasite resistance, lb	125	136
Total resistance, lb	1,265	598
L/D at landing angle	3.15	7.18
Tractive resistance, lb	440	500
Traction coefficient	0.104	0.119

Applying the formula previously given for the length of landing run gave values of 560 and 750 ft. respectively for the two machines. The actual test results were 539 and 711 ft respectively. These results, even though based only upon two tests, are encouraging. It would seem that, with reasonable accuracy in the assumptions, concordance can be expected between the actual length of the run and the computed results such as are indicated.

It is interesting to review these results. A hasty consideration of the two machines might have led to the conclusion that the R-4-L machine, with its lower landing speed, higher tractive resistance and uglier design, would have had a much shorter landing run than that of the HA machine, whereas the latter actually had a shorter run. This can be explained only by the fact that the HA machine can be set down at a larger angle, and the wings thus furnish an enormous resistance. It is the importance of a large angle of incidence for the wings which is emphasized.

It is interesting in this respect to quote from some experiments made by the British Royal Aircraft Factory. Tests were conducted on the B.E. 2c and R.E. 7, two well known British machines, for the purpose of finding the distance run after landing and the total space required after clearing a 6-ft hedge.

The measurements were made by stretching a tape 6 ft. above the ground, as at b in Fig. 1. The pilot maneuvered the machine so as to clear this, and its height above the tape, h, was observed from the ground. An observer in the machine read the air speed, V_1, and then read V_2 when the wheels touched the ground. The distances ac and cd were then measured, d being the point directly below the propeller boss where the machine stopped. The calmest days were chosen for the experiments. The landings were made against the wind and the wind velocity was recorded.

Experiments on the B.E. 2c were repeated with an arrangement such that with the tail on the ground the angle of incidence was increased. The alteration made was to shorten the top longitudinals of the rear part of the body and thus raise the skid. The increase in the angle of incidence was 3 deg. and the total space required for landing was 20 per cent less than with the standard arrangement, the distance run after touching the ground being reduced by about 35 per cent.

The following were the average values for a good landing over a 6-ft. hedge, with no wind:

	ac	cd	ad
B.E. 2c standard machine	200	550	750
B.E. 2c machine with tail raised	200	400	600

No very exact data are available on the B.E. 2c machine. The B.E. 2 machine, from which it was developed, weighs 1650 lb., has a landing speed of 40 m.p.h. and a parasite resistance of 87.5 lb. at 60 m.p.h. The machine is only moderately neat in design. These figures are merely interesting as giving a general idea of the length of landing run for a smaller and slower machine.

The Propeller on a Landing Run

Some difference of opinion exists as to the proper method of handling the engine to insure a short run. If the speed of the engine is maintained above a given number of revolutions per minute, the propeller will continue to develop a positive

* Excerpt from a paper presented at the Aeronautic Meeting of the Society of Automotive Engineers, March 10, 1920

thrust. If the engine can be throttled to a lower speed, the propeller may develop a negative thrust. If the engine is completely dead, and at rest, the propeller will offer resistance because of its resistance-producing area. When the engine is dead but the propeller is still revolving, the braking effect of the propeller acting as a windmill or air turbine may be important, but only when the forward speed is very great, as on a dive.

Let us consider whether any appreciable braking effect can be secured by running the engine on the ground at a very low speed, instead of completely stopping it. As an example, take propeller No. 5 of Dr W F Durand's report No. 14 for the National Advisory Committee for Aeronautics. Assume it to have a diameter of 9½ ft and that it is used with a Liberty engine having a maximum speed of 1700 r p m. in level flight near the ground. The V/nD ratio at a speed of 110 m.p.h., which closely approximates the case of the Curtiss R-4-L machine, is $\frac{110 \times 1\,46}{27\,4 \times 6.5} = 0\,62$. In this ratio V is the airplane speed in miles per hour, n the engine speed in revolutions per minute and D the propeller diameter in feet. The thrust coefficient from Plate VI in Dr Durand's report is 0.55 and the thrust is given by the formula

$$T = \frac{T_c D^2 V^2 \Delta}{100}, \text{ where}$$

$$\Delta = 0\,0761, \text{ the density of the air}$$

Applying the formula

$$T = \frac{0.55 \times (6.5)^2 \times (160)^2 \times 0.0761}{100} = 965 \text{ lb}$$

The torque coefficient is 0 78 so that the torque is

$$Q = \frac{Q_c D^3 V^2 \Delta}{1000}$$

$$= \frac{0\,78 \times (9\,5)^3 \times (160)^2 \times 0\,0761}{1000}$$

$$= 1270 \text{ lb.-ft.}$$

The power under the above conditions is 410 hp, which the Liberty engine can just develop The efficiency is 69 per cent, showing that the propeller would be fairly suitable for the R-4-L Curtiss machine.

In the National Advisory Committee's Report No. 30, results are given for the same propeller at negative thrust for

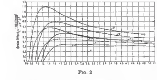


Fig. 2

very high values of V/nD. Suppose we consider 52 m.p h. the landing speed of the R-4-L machine. The negative thrust as given by the formula is

$$\frac{(\text{Brake-effect coefficient } \Delta D^2 V^2}{100}$$

and its maximum value occurs at a value of V/nD of approximately 1 8 when the brake-effect coefficient has a maximum value of 0 45 The engine speed for this value of V/nD must be 270 r p m and the thrust will be

$$\frac{0\,46 \times (9.5)^2 \times (76)^2 \times 0.0761}{100} = 182 \text{ lb}$$

No power curves are given for the test and the objection might be made that to produce this negative thrust, the Liberty engine would have to develop more power than it can deliver at 270 r p m. The negative thrust as thus developed is only equivalent to 24 hp., however, and if the V/nD ratio were decreased to 1 2 by increasing the engine speed to 405 r.p.m., the negative thrust would still be 127 lb

The Durand propeller No. 5 was selected quite at random, and yet the maximum possible thrust is found to be 182 lb. for the landing speed of the R-4-L machine. Since this is about 40 lb more than the skid drag of the same machine, it is by no means negligible, but this propeller is not a very good illustration of what it is possible to do with a propeller in the region of negative thrust. In the curves of Fig 2, taken from Plate XXX of Report No. 30, it is seen that the brake-effect coefficient at its maximum is not so very much greater than the approximately asymptotic value of the coefficient, at very high values of V/nD when the number of revolutions per minute becomes very small. With such a propeller, the maximum brake-effect coefficient would therefore not be so very much

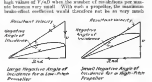


Fig. 3

greater than if the propeller were not revolving, and thus opposing forward motion simply by virtue of its resistance area.

But the brake-effect coefficient of propeller No 10, as indicated in the same series of curves, is more than twice as great as that of propeller No. 5, and at an airplane speed of 52 m.p h., a V/nD ratio of 1.2 and engine speed of 410 r p m., would, with the same propeller diameter of 9½ ft., give a negative thrust of 400 lb, which would check the landing run very rapidly. Moreover, propeller No 10 has a maximum brake-effect coefficient much greater than the value shown on the curves for very large values of V/nD and approaching the condition of a non-revolving propeller.

The investigation of Report No 30 indicates that for a given size of propeller, wide blades have a larger brake effect than narrow blades, and that the brake effect of the higher-pitch propeller is less than that of the lower-pitch propeller. The latter result is quite reasonable as can be seen from the diagrammatic representation in Fig 3, since with a low-pitch propeller the tendency will be for the air to strike the propeller blade element at a larger negative angle to the chord.

An objection might be made that as the landing run proceeded and V decreased, the V/nD ratio would decrease so that the pilot would run the propeller into a region of low brake-effect coefficient, or even of positive thrust, and it is quite possible that pilots may at first find considerable difficulty in getting the best braking effect. But with a broad-blade, low-pitch propeller, it seems quite conclusive that pilots would find an advantage in experimenting on their landing run until they found the best possible combination. The shortening of the landing run resulting therefrom might make all the difference between a poor and a good commercial machine.

Devices for Shortening Landing Runs

The most obvious device for shortening a landing run is the use of an airbrake consisting of flat plates hinged at the sides of the fuselage. To avoid the effort which is required to operate such brakes, it is advisable to have the brake plates arranged so that the relative wind will force the side plates to open while the opening of the under flap is retarded by the wind. A fairly simple arrangement for the control of such an airbrake is shown in Fig 4. This type of brake has been used on British machines, but objections can be raised to its employment on the grounds of complication and also that the resistance of the brakes diminishes rapidly as the speed decreases.

In a British test, the model body RE-1, shown in Fig 5, had

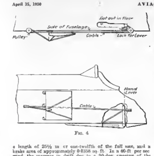


Fig. 4

a length of 25½ in or one-twelfth of the full size, and a brake area of approximately 0 0358 sq. ft. In a 40-ft per sec wind, the increase in drift due to a 90-deg opening of the brakes was 0 0804 lb, giving a brake-effect coefficient of 0 003 per sq ft. per m p h. This indicates that airbrakes will offer practically the same resistance as flat plates freely exposed.

The full-size area of the brakes for the RE-1 is 5.15 sq. ft Imagine brakes of 10-sq ft. area applied to the Curtiss R-4-L machine, whose landing run has been previously discussed and which is a larger machine than the RE-1. The resistance at 52 m.p.h. will be 81 5 and the L/D ratio becomes 6 3. The calculated run now becomes 680 ft. instead of the 750 ft. previously computed It is quite clear from this that the effect of airbrakes is small, and hardly worth inclusion On a very small machine it is possible that brakes of a large size relative to the wing area might be included with more satisfactory results.

While airbrakes may be set aside as entirely unpromising, the use of wing flaps extending over almost the entire trailing

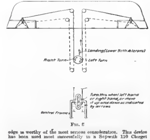


Fig. 5

edge is worthy of the most serious consideration. This device has been used most successfully in a Sopwith 110 Clerget single-seat seaplane and in a seaplane built by the Fairey Aviation Co A diagrammatic scheme for a proposed employment of wing flaps without disturbing the functions of the ailerons is shown in Fig 6.

In some British experiments carried out on an R.A.F.9 wing section with the hinged rear portion occurring at 0.385 of the chord, the maximum lift obtainable was increased in the ratio of 1.35 to 1, the flap being set at 60 deg. to the wing. This maximum lift occurs when the angle of incidence of the wing proper is in the neighborhood of 4 to 6 deg Such an increase in the maximum lift would decrease the landing speed in the ratio of 1 to 0 865. If the flap were used intelligently by the pilot, it could be used effectively as a brake, after the machine had settled at a speed and attitude corresponding to the maximum lift, by being set at a maximum pitch of 90 deg. to the wing, with the wing itself at an attitude corresponding to the three-point landing Even when the flap was only set at a 45-deg positive angle to the wing, the drift of the R A.F 9 at 14 deg was increased in the ratio of 5 45 to 1.

If the mechanism were applied to the Curtiss R-4-L machine and used as already explained, with flap set at a positive 60-deg angle for landing and a positive 90-deg angle for braking, the landing speed would become 45 m.p h. and the landing run would be reduced to about 200 ft., as compared with the 750 ft previously computed A definite conclusion would be that wing flaps extending along the rear edge would be of very appreciable help.

It is very often assumed that a variable-pitch propeller will

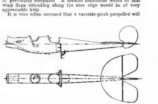


Fig. 6

decrease the landing speed by imposing a large negative thrust on the airplane in the dive A short consideration of the problem will indicate that this conception is erroneous.

For small angles of glide the effect of a negative propeller thrust will be simply to increase the angle of glide for any speed of glide of the machine. It is only on a very steep, almost vertical, dive that the negative thrust will act usefully by keeping down the terminal velocity On recovery from the dive, the negative propeller thrust will have no effect upon the landing speed, which will always be defined by the maximum K_y of the plane. The variable-pitch propeller will, however, have a very powerful effect indeed on the landing run and will be probably the most efficacious method of braking possible

In Fig 7, the forward skid arrangements for the English Avro and the Ace machines are shown. Such arrangements are equivalent to the placing of an extra tail-skid and an extra tractive effect, without the inconveniences entailed in carrying the center of gravity far behind the wheels, which means difficulties in get-away and a damaging effect on the field due to an extremely heavy tail-skid load If, in the Curtiss R-4-L machine, the skid tractive effect of 140 lb. were increased to 280 lb by the use of a forward skid, the computed run would be shortened to 615 ft instead of 750 ft., which is an appreciable difference.

Brakes on wheels have been avoided hitherto because of the tendency induced of nosing the machine over, but with a small forward wheel or skid they might become a very useful device.

Length of Get-Away

It is much more difficult to arrive at an exact determination of the length of the get-away run owing to the fact that the attitude of the machine may change during the run, and also because the thrust of the propeller varies during the run. For every machine there is undoubtedly a best attitude for the

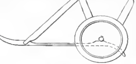


FIG. 7

get-away and a best method for attaining the quickest get-away. In the comparative test of the Curtiss HA and R-4-L machines previously mentioned, the tractive resistances were

	HA	R-4-L
With tail-skid dragging lb	440	300
With tail-skid set in a two-wheel truck lb	240	208

This indicates quite clearly that the pilot should get the skid off the ground as soon as possible and thereby remove a considerable portion of the tractive effort. Unless the center of gravity is very far back of the wheels, this should be possible almost as soon as the engine is fully effective and the slipstream of the propeller hits the tail surfaces.

When the plane starts off, the equation of motion becomes

$$\frac{W d^2x}{g dt^2} = T - cV^2 - c_1(W - c_2 v^2)$$

The notation is the same as that previously employed and T is the thrust of the propeller. The resistance to movement can be expressed by the formula

$$(c_1 - c_2 c_3)\, v^2 + c_1 W$$

Since $c_1 W$ is a constant, the acceleration will be a maximum when $(c_1 - c_2 c_3)$ is a minimum. To find the attitude at which this is a minimum, graphical methods are best employed. Taking the HA machine for which the tractive coefficient without skid drag is 0.06, the Curtiss Company's performance computations for a load of 3994 lb give the curve of Fig. 8. It is seen that the minimum value of $c_1 - c_2 c_3$ occurs in the neighborhood of 4 deg., at which also occurs the best L/D ratio for the machine. This is what might be expected on general grounds. With the skid off the ground, the tractive coefficient is so low that it will not pay to reduce the reaction on the ground by lifting on the wings. At the same time, if the machine were taken off at too small an angle, the L/D ratio of the wings is too low.

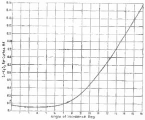


FIG. 8

An investigation of the R-4-L machine figures gives a similar result. The computations indicate as correct on theoretical grounds the procedure adopted in a get-away by the best pilots, namely, a quick lifting of the tail and a subsequent run at a small angle of incidence until the flying speed is attained.

The design of the propeller has a certain influence on the length of get-away, although it is difficult to reconcile a propeller working efficiently on the get-away with satisfactory performance in speed and climb. The broad rule for a quick-get-away propeller is to have the diameter small enough so that the engine can attain as high a number of revolutions per minute on the ground as possible, as the thrust increases rapidly with the speed of revolution. Propellers of smaller pitch generally have the larger thrust-power ratio, and wide-blade propellers generally have larger thrust-power ratios also, as indicated in Dr. Durand's tests.

The variable-pitch propeller will be of great value in securing a speedy get-away, since the pitch can be made small on the ground, while in level flight it can be made suitably high. Much practical and theoretical work remains to be done before the full possibilities of the variable-pitch propeller can be realized.

No attempt has been made in the course of this paper to compute the length of get-away. To do this, it would be necessary to know the characteristics of the propeller at low ratios of V/nD and at static thrust, and either to solve the equation of motion by integration for the intervals during which the propeller thrust would be constant, or by putting the thrust into the equation as a function of the velocity. I hope to work out this problem for a typical machine at a later date. The question of the length of get-away offers less difficulties in commercial flying than the landing run, since for the get-away there can be a better selection of ground. In the comparative test on the HA and R-4-L machines, the get-away distances were 538 ft. for the HA and 524 ft. for the R-4-L machine. On the landing run the HA machine was better, owing to the larger angle of incidence that could be maintained in rolling on the ground, but the R-4-L machine made a quicker and shorter get-away because of its lower minimum flying speed.

Some Wind Tunnel Data

It appears from wind tunnel experiments that the center of pressure on surfaces is independent of speed for practical purposes and that wing coefficients vary with speed and scale. These coefficients are not constant. The lift coefficient is *practically constant*, but the resistance coefficient for a wing at small angles decreases with speed and scale. At large angles the coefficient is nearly constant. As a rough rule, take about 87 per cent of model K_x at value of minimum K_x and 100 per cent at 15 deg. and correct intermediate values in proportion.

The lift on ailerons on upper plane of a biplane is a maximum at 15 deg. For a monoplane the maximum lift is at 60 deg. Aileron surface on a biplane is about three-fifths as effective as on a monoplane.

Pitching moments on the tail plane may be estimated as if tail plane were in clear air and then using one-half of result.

Damping of pitch due to tail is 80 per cent of total of wings, 5 per cent of total; of body, 15 per cent of total.

Resistance of rear struts of biplane is 80 per cent of value computed as in free air.

For wing area in propeller race add 5 per cent to lift computed for free air.—Comdr. J. C. Hunsaker, C. C., U. S. N. Aircraft Technical Note. Bureau of Construction and Repair, Navy Department.

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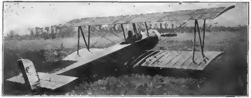

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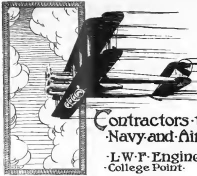

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State of New York }
County of New York } ss.

Before me, a Notary Public in and for the State and county aforesaid, personally appeared Lester D. Gardner, who, having been duly sworn according to law, deposes and says that he is the Editor of the AVIATION AND AERONAUTICAL ENGINEERING and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management, etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, embodied in section 443, Postal Laws and Regulations, printed on the reverse of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business managers are:
Publisher, The Gardner-Moffat Co., Inc., 22 East 17th Street, New York; Editor, Lester D. Gardner, 22 East 17th Street, New York; Managing Editor, Ladislas d'Orcy, 22 East 17th Street, New York; Business Managers, H. M. Williams, George Newbold, 22 East 17th Street, New York.

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L. D. GARDNER.

Sworn to and subscribed before me this 29th day of March, 1920.

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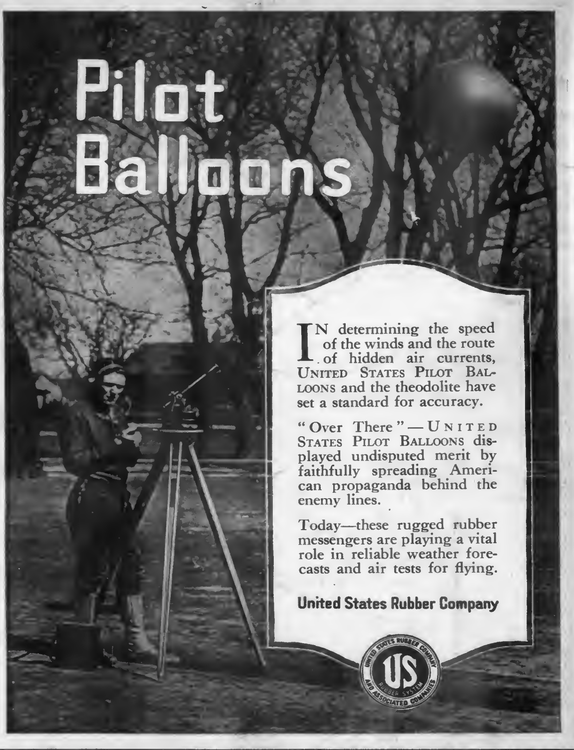

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